AD-A071 068 ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY ABERDEEN PROV--ETC F/G 13/6
A COMPARISON OF MAINTENANCE COSTS AND RAM CHARACTERISTICS OF NE--ETC(U)
JAN 79 R BELL, R MIODUSKI, E BELBOT

UNCLASSIFIED AMSAA-TR-251 NL

| OF |

AD
A071068

END
DATE
FILMED
8-79
DDC

AD A071068

LEVEL II

AMSAA

TECHNICAL REPORT NO. 251

A COMPARISON OF MAINTENANCE COSTS AND
RAM CHARACTERISTICS OF NEW AND OVERHAULED
M35A2 2-1/2 TON TRUCKS

RAYMOND BELL
ROBERT [illegible]
EDWARD [illegible]

JANUARY 1978

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

U.S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
ABERDEEN PROVING GROUND, MARYLAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

9 Technical rept.,

REPORT DOCUMENTATION PAGE | READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER TR- 251	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 A Comparison of Maintenance Costs and RAM Characteristics of New and Overhauled M35A2 2-1/2 Ton Trucks.		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Raymond Bell Robert Mioduski Edward Belbot		8. CONTRACT OR GRANT NUMBER(s) 12 48p.
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Materiel Systems Analysis Activity Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 DA Project No. 1R765706MS41
11. CONTROLLING OFFICE NAME AND ADDRESS Commander US Army Materiel Development & Readiness Command 5001 Eisenhower Avenue Alexandria, VA 22333	11	12. REPORT DATE January 1979 13. NUMBER OF PAGES 51
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; unlimited distribution.

14 AMSAA-TR-251

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

2-1/2 ton Truck
RAM
Maintenance Costs

403 910 Gm

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A comparison of the maintenance costs, and reliability, availability and maintainability (RAM) characteristics of new and overhauled 2-1/2 ton trucks is presented. This comparison was based on the performance of 259 new and 252 overhauled M35A2 2-1/2 ton trucks operated by the 9th Infantry Division, Ft. Lewis, Washington, over a four year period. The 511 vehicles evaluated in in this study accumulated a total of 2.7 million miles with the individual new and overhauled vehicles accumulating mileage histories up to 19,000 and 11,000 miles, respectively.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

CONTENTS

Next page is blank.

LIST OF ILLUSTRATIONS

LIST OF TABLES

ACKNOWLEDGEMENT

A number of persons have significantly contributed to the completion of this study and the authors wish gratefully to acknowledge the participation of each. In particular, they would like to acknowledge the assistance of the Vehicle Useful Life Study Advisory Group including LTC R. Healy, DSCLOG, the current chairman of the Group; LTC R. Webster, DSCLOG, the previous chairman of the Group; LTC K. Halleran and MAJ J. Hughes, DARCOM, CAPT R. Sirtak, TARCOM and Mr. E. Jackson, MRSA. The authors also express their gratitude for the technical aid received from personnel of the Management Information Systems Support Division of ARRADCOM, especially Messrs. Glen Beck, Monte Coleman, and George Thompson.

Next page is blank.

A COMPARISON OF THE MAINTENANCE COSTS AND RAM CHARACTERISTICS
OF NEW AND OVERHAULED 2-1/2 TON TRUCKS

1. EXECUTIVE SUMMARY

1.1 Problem.

To compare the maintenance costs and RAM characteristics of new and overhauled 2-1/2 ton trucks.

1.2 Approach.

The comparison of the maintenance costs and RAM characteristics of new and overhauled 2-1/2 ton trucks was determined by assessing the performance of a group of new M35A2 2-1/2 ton trucks with a similar size group of overhauled 2-1/2 ton M35A2 trucks. These two groups of trucks were operated under the same general conditions by field units. The comparison focused on comparing the maintenance costs and RAM characteristics as the vehicle's mileage increased.

1.3 Discussion.

The study was based on the performance of 259 new and 252 overhauled M35A2 2-1/2 ton cargo trucks operated at the 9th Infantry Division, Ft. Lewis, Washington, from October 1973 through June 1977. The new vehicles contained in the study had accumulated 1.4 million miles over this four year period with individual vehicles accumulating mileage histories up to 18,000 miles. The overhauled vehicles assessed in the study accumulated 1.3 million miles over this same time frame with individual vehicles accumulating mileage histories up to 11,000 miles.

1.4 Conclusions.

No significant difference was found in either the maintenance costs or the RAM characteristics between the new and overhauled 2-1/2 ton trucks over the mileage intervals compared. For example, the average new 2-1/2 ton truck will sustain a total maintenance cost (for both scheduled and unscheduled maintenance) of $5,135 (1977 dollars) during the indicated initial 20,000 miles of usage, for an average maintenance cost of 26 cents per mile. Over the same mileage, the overhauled 2-1/2 ton truck will cost $4,920 to maintain, for an average maintenance cost of 25 cents per mile. From a RAM standpoint, it has been determined that an average new truck will have a .96 probability that it will not be undergoing repair due to an unscheduled maintenance action at any random point in time with a .97 similar probability for an average overhauled truck. In addition, the overall probability of completing a 75 mile mission without having to have an unscheduled repair is .89 for the new vehicle and .92 for the overhauled vehicle. As a further indication of the similarity of the new and overhauled vehicle from a RAM standpoint, the average new vehicle was shown to require 15.7 man-hours per truck per 1,000 miles as compared to 14.6 man-hours for the overhauled truck.

1.5 Recommendations.

It is recommended that the Army consider overhauling as a possible means of fulfilling its 2-1/2 ton truck needs. The feasibility of overhauling not only must take into consideration maintenance costs and RAM characteristics but also must evaluate procurement versus overhaul costs and other pertinent management considerations.

2. INTRODUCTION

In a move by the Department of Army (DA) to reassess the useful life of the tactical wheeled fleet, the Army Materiel Systems Analysis Activity (AMSAA) was tasked by the Army Materiel Development and Readiness Command (DARCOM) Plans and Analysis Directorate to conduct a Vehicle Useful Life Study which would have the following primary objectives:

a. Determine the age (mileage) at which it becomes economical to replace each of the four major payload tactical wheeled vehicles (1/4, 1-1/4, 2-1/2 and 5 ton vehicles).

b. Determine the economics of overhauling wheeled vehicles and the remaining life after overhaul.

This report, which is the fourth report pertaining to these objectives (see AMSAA TM No. 164, TR No. 128 and TR No. 219 for the useful life determination of the 2-1/2 ton, 5 ton and 1/4 ton trucks, respectively), provides input to a possible decision on the economics of overhauling the 2-1/2 ton truck by comparing the maintenance costs and RAM characteristics of new and overhauled vehicles.

3. DATA SOURCES

The data sources being utilized in this study consist of two separate Army data collection systems: (a) The Army Integrated Equipment Record Maintenance Management System (TAERS) and (b) Sample Data Collection (SDC). The Army Maintenance Management System (TAMMS) which succeeded TAERS, did not record maintenance actions for tactical wheeled vehicles and was, therefore, of no value for the study. The TAERS data collection system for vehicles was instituted by the Army in 1963 and was designed to collect detailed maintenance information on all vehicles in the U.S. Army fleet. This data collection system, however, was terminated in December 1969. The SDC program for vehicles was initiated in 1972 and was also designed to collect detailed maintenance data, but only for a sample portion of the wheeled vehicle fleet. The SDC program also differs from TAERS in that the U.S. Army Tank-Automotive Readiness Command (TARCOM) technical representatives who are in the field will monitor the data collection effort in order to insure that there is more complete reporting of data than occurred under TAERS.

The TAERS data were the primary data source for the first objective of the Vehicle Useful Life Study, namely, reassessing the useful life of the four major payload vehicles. Since no appreciable

quantity of data for overhauled vehicles exists in TAERS, the SDC program thus became the main source of data for determining the comparison of maintenance costs and RAM characteristics of new and overhauled 2-1/2 ton trucks.

4. VEHICLE SAMPLE

The principal data used in the study were obtained from SDC reporting on 259 new (non-overhauled) and 252 overhauled M35A2 2-1/2 ton cargo trucks operated from 1973 to 1977 by the 9th Infantry Division at Ft. Lewis, Washington. It should be noted that the 252 overhauled vehicles included in this study were subjected to a "limited depot overhaul" during the overhaul process, i.e., all vehicle components were either replaced or repaired on an as required basis only. This is determined from an individual inspection of each vehicle. This should not be confused with a rebuilding process where the vehicle is automatically stripped to the frame and all new/rebuilt parts are reassembled to the vehicle (AR 750-1). No rebuilt vehicles were included in this study. A summary of the number of vehicles and the total accumulated mileage appears below.

TABLE 4.1 - NUMBER OF VEHICLES INCLUDED IN STUDY

M35A2 2-1/2 TON CARGO TRUCK

	No. Vehicles	Total Mileage (Millions)
New	259	1.4
Overhauled	252	1.3
TOTAL	511	2.7

The M35A2 2-1/2 ton cargo truck was deemed suitable as the subject vehicle for this analysis since this body type represents the major portion of the 2-1/2 ton fleet. Ft. Lewis was selected as the data collection site for two principal reasons (1) the 9th Infantry Division was being relocated at Ft. Lewis at the initiation of this study and it was thus opertune to place the sample vehicles, particularly the overhauled in cross section of the division; and (2) the Ft. Lewis site (including the Yakima training area) encompasses a broad variety of terrain (flat surfaces, mountains, desert areas) and weather conditions (hot, dry desert conditions to cold, rainy conditions). The vehicle sample comprised of overhauled vehicles that were randomly selected from an existing Army overhaul operation, i.e., they were not specially overhauled for this study while the new vehicles in the study were randomly assigned new 2-1/2 ton trucks from the Army stockpile.

5. VEHICLE DESCRIPTION

The M35A2 truck is a 2-1/2 ton, 6x6, Cargo Truck with a 12 foot stake bed, steel body. The body is equipped with auxiliary sills to raise the floor above the tires to eliminate the raised wheel housing on similar vehicles. The maximum inside width of the flat bed on the M35A2 body is 88 inches. Removable wooden cargo racks may be mounted at the front and sides of the body. The lower portion of the side racks can be lowered for use as seats when the vehicle is used as a troop carrier. Sockets are provided for the installation of top bows and tarpaulin. The rear of the body is closed by a hinged end gate.

The cab is a metal open-top structure, which surrounds the driver's compartment. A two piece windshield, which may be folded forward is mounted at rear of cowl. The cab is furnished with an adjustable driver's seat and a companion seat. Doors are provided in the lower portion of the front panels. The open type trucks are provided with either a canvas or a hardtop.

The power plant consists of the model LD 465-1 six cylinder, in line, overhead valve, liquid cooled, multifuel, compression ignition engine. Accessories such as air compressor, fuel pumps, generator oil filters, starter and clutch are mounted on the engine. The clutch is a single dry plate type attached to the engine flywheel. The transmission, mounted at the rear of the clutch, has five speeds forward and one reverse. The transfer is a two speed unit, driven by the transmission, which distributes power through propeller shafts to the front and rear axles.

The chassis is equipped with one driving front axle and two driving rear axles. All axles are bevel drive, top mounted, double reduction, single speed type. Constant velocity universal joints for driving the front wheels are incorporated into the steering knuckles.

6. METHODOLOGY

The methodology used in this study consisted of two principal phases. First, the maintenance costs for overhauled M35A2 2-1/2 ton Cargo Trucks were compared to the maintenance costs for new M35A2's as a function of mileage (Stonier, et al., 1953). Secondly, the reliability, availability and maintainability (RAM) characteristics of the new and the overhauled vehicles, and the parts replaced for each, were examined and compared. This second phase was necessary to isolate such possible difficulties as frequent breakdowns due to failure of relatively inexpensive parts. The effects of such breakdowns might not be apparent in the cost analysis, but might cause substantial degradation in RAM performance.

7. DATA ANALYSIS

As noted earlier, SDC data were the data source used in this study for both the maintenance costs and RAM comparisons. This data

base provided information on maintenance actions (both scheduled and unscheduled) required for the trucks as they increased in mileage. Specifically, for each maintenance action, the following data were recorded: date action occurred, mileage at which action occurred, maintenance level (organization or support), man-hours used, remedial action taken (repaired, replaced, adjusted, services), part name, National Stock Number, and quantity of parts replaced. The SDC histories were subjected to the same automated error screening and correction system previously used to purify the TAERS histories, as documented in Belbot, 1975. The SDC histories did not contain the serious data discrepancies which were detected in the TAERS histories and reported in Bell, et al., 1973; Bell, et al., 1975; and Bell, et al., 1977. Prior to use of the data, the few histories containing errors were deleted. The corrected histories remain in AMSAA's tape archives.

The maintenance cost comparison was carried out in 1977 dollars and was based on parts costs contained in the Army Master Data File and a mean labor rate of $6.61 per hour. In the costing of the maintenance actions by the mileage, it was necessary to be aware of each vehicle's mileage interval because the costing procedure involved determining the total cost (parts and labor) experienced by the vehicles for each 100 mile interval. This was particularly critical because the vehicles involved in the study had histories beginning and ending at various different mileages and further the number of vehicles in each 100 mile interval differed. This costing procedure conservatively estimates the costs sustained since each vehicle contributes information only to those mileage intervals covered by its maintenance history, rather than contributing to mileage intervals beyond the last maintenance action recorded, on the assumption that the vehicle traveled some additional miles without maintenance. For example, a vehicle for which the maintenance history ended at 5,169 miles, would contribute data up through the interval 5,101 to 5,200 miles. In fact, this vehicle would probably travel more than the 31 miles allowed by the procedure before requiring maintenance, since the mean miles between stops for maintenance (scheduled or unscheduled) was observed to be 249 miles for the overhauled M35A2's and 288 miles for the new M35A2's.

The RAM analysis presented an additional problem in the analysis of the SDC data. Normally in the analysis of data for the determination of reliability and availability estimates, failure data are required. However, from the SDC histories it was not possible to determine for all unscheduled maintenance actions which actions were reliability failures. As a result of this fact, an analysis of all unscheduled maintenance actions was undertaken rather than the usual analysis of failures. Specifically, the analysis consisted of three phases, all with the objective of determining how the performance of the new and the overhauled vehicles compared as the vehicles increased in mileage: (1) unscheduled maintenance action analysis - the goal of this analysis was to determine the probability of completing 75 miles without an unscheduled maintenance action (UMA) for continaully increasing mileages, (2) inherent readiness analysis - the object of this analysis was to determine as a function of mileage, the probability that the vehicle is not undergoing active repair

due to an unscheduled maintenance action when required for use at a random point in time, and (3) maintainability analysis - this analysis consisted of determining, as a function of mileage, the maintenance support index (MSI), the average man-hours required per maintenance action.

8. COST ANALYSIS

The analysis of the cost data (see Tables 8.1 and 8.2) involved the determination of continuous instantaneous maintenance cost curves (the instantaneous maintenance cost refers to the maintenance cost per mile at a particular mileage), by means of weighted regression analysis techniques (see Appendix A). Weighted regression was required since the number of vehicles in each mileage interval was not a constant. Vehicles with higher usage rates covered more miles during the 3 year reporting period than low usage vehicles. The following instantaneous maintenance cost models were obtained from the regression analysis as yielding the smallest standard deviations of residuals from among the polynomial, logarithmic and exponential models possibly appropriate for the data:

$$f_N(X) = .226 + .613 \text{ EXP } (-X/1000)$$

and

$$f_O(X) = .214 + .646 \text{ EXP } (-X/1000)$$

where

$f_i(X)$ = instantaneous maintenance cost (dollars per mile)

X = mileage

i = N for new, O for overhauled

and

EXP(Z) = exponential function evaluated at Z. All coefficients were significant at the .001 level.

These curves are presented in Figure 8.1 in a comparison plot. Both curves indicate high maintenance costs during the first 2,000 miles, however, the costs level off after 3,000 miles, and become approximately constant thereafter. The high initial costs have been attributed to initial quality control problems in the new and the overhauled vehicles.

From the continuous instantaneous maintenance cost curves, the cumulative maintenance cost curves were obtained by analytic integration, rather than by numeric integration. The functions determined were:

$$F_N(X) = .226X - 612.77 \text{ EXP } (-X/1000) + 612.77$$

and

$$F_O(X) = .214X - 646.32 \text{ EXP } (-X/1000) + 646.32$$

where

$F_i(X)$ = cumulative maintenance cost (FY 77 dollars)

X = mileage

i = N for new, O for overhauled

and

EXP(Z) = exponential function evaluated at Z.

In Figure 8.2, the cumulative maintenance cost curves of the new and the overhauled vehicles are compared. Through an extrapolated 20,000 miles of usage, the new truck is indicated to have a cumulative maintenance cost of $5,135 while the overhauled truck has a cost of $4,920. As may be seen in the graph, the cumulative maintenance costs for the new and the overhauled vehicles are almost identical.

In summary, from a maintenance cost standpoint, there is no detectable difference between the new and the overhauled M35A2 2-1/2 Ton Cargo Truck, based upon the data available, the curves developed, and the statistical tests applied. In addition, although separate instantaneous maintenance cost curves are presented for the new and the overhauled vehicles, statistical tests for comparing two regression lines (see Appendix B) indicated no significant difference between the cost curves at the .05 level of significance.

9. PERFORMANCE ANALYSIS

9.1 Unscheduled Maintenance Action Analysis.

As indicated earlier, in place of a reliability failure analysis, an analysis of all unscheduled maintenance actions was carried out. This process was necessary because the SDC histories indicate replacements and repairs, but do not indicate if the parts in question had failed or had merely showed signs of possible future failure, or if failure of the subject parts would result in a mission abort.

In analyzing the unscheduled maintenance actions, a system Weibull failure rate function was applied. The rate of unscheduled maintenance actions at mileage x is r(x) where

$$r(x) = \lambda\beta x^{\beta-1} \qquad x > 0,\ \lambda > 0,\ \beta > 0$$

x = mileage on vehicle

λ = scale parameter

and β = shape parameter

TABLE 8.1
COST DATA FOR NEW M35A2 CARGO

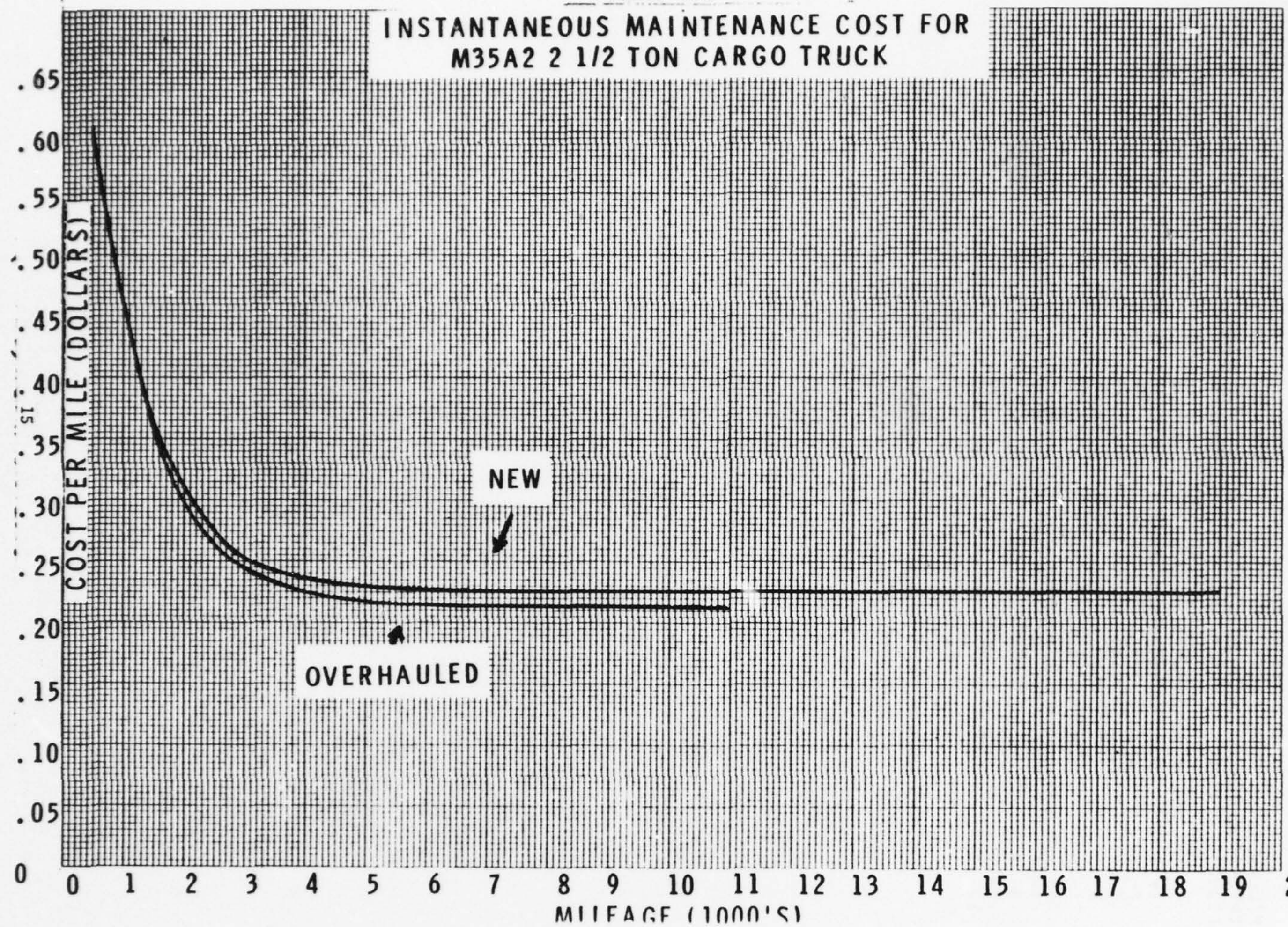
MILEAGE INTERVAL (1000'S)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. + UNSCH.)	NO. OF MAN-HRS	TOTAL LABOR COST (DOLLARS)	TOTAL PARTS COST (DOLLARS)	TOTAL COST (DOLLARS)	AVG-COST PER TRUCK PER 1000 MILES (DOLLARS)
0- 1	51	1,329	2,052	13,564	15,967	29,531	579
1- 2	107	2,221	2,304	18,534	17,059	35,593	333
2- 3	125	2,250	2,806	18,550	16,698	35,248	282
3- 4	138	1,986	2,425	16,037	10,437	26,474	192
4- 5	130	1,729	1,938	12,808	14,233	27,041	208
5- 6	124	1,805	2,173	14,360	28,872	43,232	349
6- 7	116	1,435	1,587	10,489	8,256	18,745	162
7- 8	98	1,164	1,564	10,339	24,199	34,538	352
8- 9	83	923	1,205	7,967	21,759	29,726	358
9-10	74	689	893	5,903	8,683	14,586	197
10-11	60	698	736	4,865	6,696	11,561	193
11-12	48	600	690	4,561	9,468	14,029	292
12-13	43	373	395	2,611	2,104	4,715	110
13-14	40	404	368	2,429	3,148	5,577	139
14-15	34	349	374	2,472	819	3,291	97
15-16	29	320	309	2,042	1,367	3,409	118
16-17	24	205	266	1,755	1,873	3,628	151
17-18	19	138	125	830	661	1,491	78
18-19	11	272	212	1,398	1,476	2,874	261

TABLE 8.2

Cost Data for Overhauled M35A2 Cargo

Mileage Interval (1000'S)	Average No. of Trucks	No. of Maint. Actions (Sch. + Unsch.)	No. of Man-Hrs	Total Labor Cost (Dollars)	Total Parts Cost (Dollars)	Total Cost (Dollars)	Avg-Cost per Truck per 1000 Miles (Dollars)
0- 1	221	5,525	7,231	47,800	80,479	128.279	580
1- 2	238	4,081	5,109	33,769	43,596	77,365	325
2- 3	208	3.436	4,134	27,324	33,529	60,853	293
3- 4	172	2,094	3,083	20,376	23,782	44,158	257
4- 5	131	1,819	1,959	12,285	25,420	37,705	288
5- 6	99	1,500	1,285	8,494	7,668	16,162	163
6- 7	79	460	801	5,295	4,315	9,610	122
7- 8	60	635	663	4,417	15,735	20,152	336
8- 9	42	306	328	2,168	1,820	3,988	95
9-10	26	161	159	1,043	1,133	2.231	86
10-11	16	66	99	651	2,677	3,328	208

FIGURE 8.1



INSTANTANEOUS MAINTENANCE COST FOR
M35A2 2 1/2 TON CARGO TRUCK
COST PER MILE (DOLLARS)
.65
.60
.55
.50
.45
.40
.35
.30
.25
.20
.15
.10
.05
0
NEW
OVERHAULED
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
MILEAGE (1000'S)

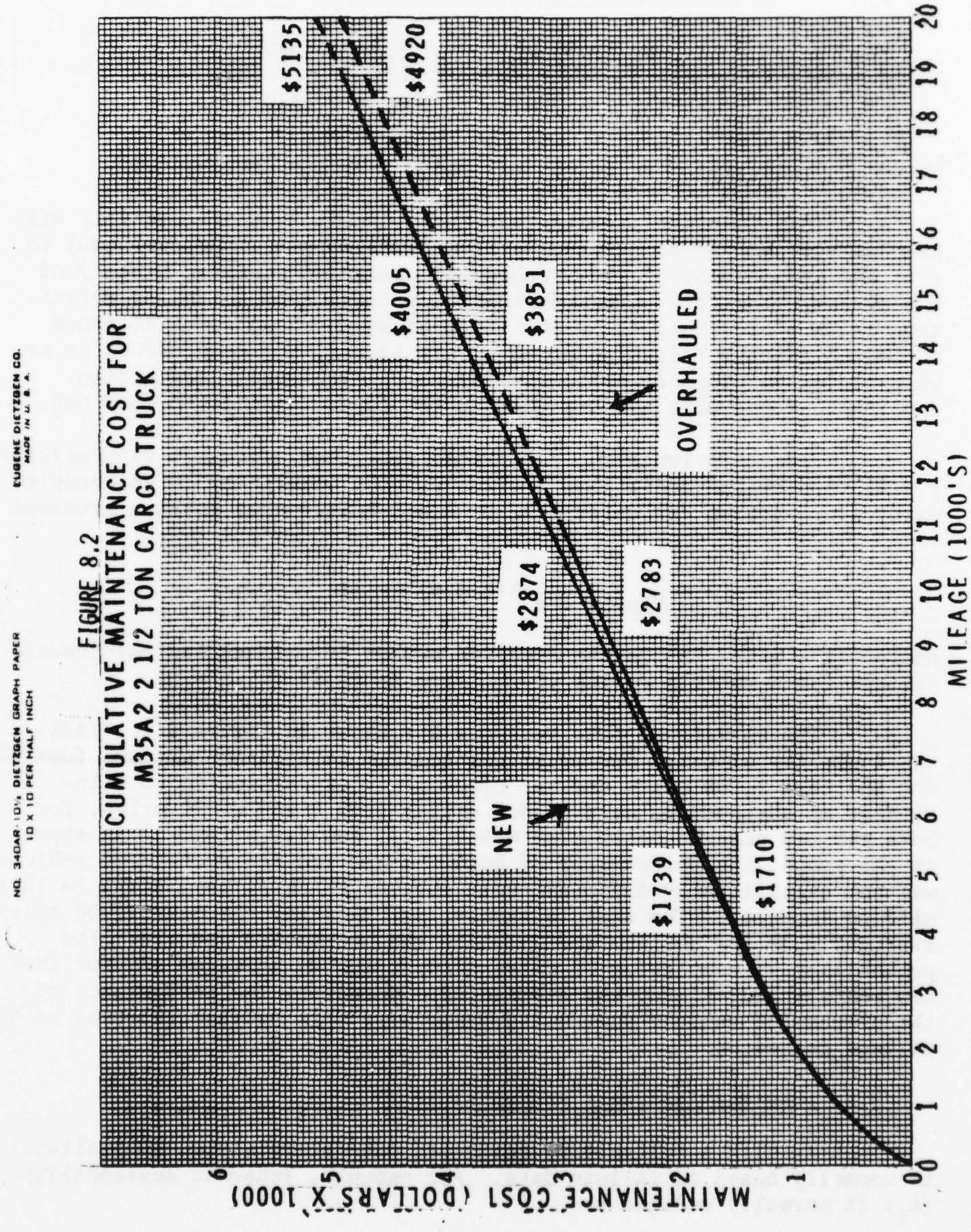


FIGURE 8.2
CUMULATIVE MAINTENANCE COST FOR M35A2 2 1/2 TON CARGO TRUCK

The maximum likelihood estimates determined (see Crow, 1975 and Belbot, 1975) for these vehicles were:

$$\beta_N = .82428 \qquad \beta_O = .58099$$

$$\lambda_N = .00906 \qquad \lambda_O = .08146$$

where the subscript N indicates new and O indicates overhauled.

This function assumes that the probability that a vehicle will have an unscheduled maintenance action at mileage t is proportional to r(t) and independent of the unscheduled maintenance action history of the system prior to t. This definition differs from the usual definition which states that the probability of an unscheduled maintenance action at mileage t is also proportional to r(t) but conditioned on no unscheduled maintenance actions prior to t. The former definition applies to repairable systems whereas the latter definition does not.

From this function, the probability that a vehicle with mileage t will complete an additional s miles without undergoing an unscheduled maintenance action (as determined by a non-homogeneous Poisson process) is

$$P(s/t) = e^{-\lambda(t + s)^{\beta} + \lambda t^{\beta}}$$

where $\lambda(t + s)^{\beta} - \lambda t^{\beta}$ is the expected number of unscheduled maintenance actions for a vehicle during the mileage interval (t, t + s).

The results of this analysis are shown in Figure 9.1. Indicated are the expected number of unscheduled maintenance actions (UMA's) for the next 1,000 miles and the probability of completing 75 miles without an unscheduled maintenance action from 0 to 20,000 miles, for both the new and the overhauled M35A2 2-1/2 ton Cargo Truck. As shown in the graph, the performance of both the new and the overhauled vehicles was not significantly different with respect to these parameters in this mileage interval. The expected number of UMA's for the next 1,000 miles averages 1.59 for the new and 1.28 for the overhauled vehicle. The probability of completing 75 miles without an UMA averages .89 for the new vehicle and .92 for the overhauled. Moreover, the performance of the overhauled vehicle does not degrade over this mileage interval as the mileage increases.

9.2 Inherent Readiness Analysis.

As with a reliability analysis, the determination of availability is normally based on failure data. For example, Inherent Availability (A_i) is normally defined as:

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where MTBF is the mean time between failures and MTTR is the mean time to repair.

As noted in previous sections of this report, unscheduled maintenance actions rather than failure data were available. Further, the SDC data provided information on the mean man-hours to repair rather than the mean time to repair. The mean time to repair for a particular maintenance action could be less than the man-hours involved if two or more mechanics worked on the action. To utilize these data, however, to obtain an estimate of an availability statistic, one can determine the probability of a truck not undergoing active repair due to any unscheduled maintenance action when called upon to operate at a random point in time (Inherent Readiness) and this is given by the following expression:

$$R_i = \frac{MTBUMA}{MTBUMA + MMHTR}$$

where MTBUMA is the mean time between unscheduled maintenance actions (assuming an average speed of 20 mph) and MMHTR is the mean man-hours to repair. It should be noted that the Inherent Readiness parameter is a lower bound on an Inherent Availability value, i.e., if all unscheduled maintenance actions were reliability failures and if no more than one mechanic ever worked on a maintenance action then the mean man-hours to repair would be equivalent to the mean time to repair and $R_i = A_i$.

The results of this analysis are shown in Figure 9.2. Indicated on this figure are the mean miles between unscheduled maintenance actions (MMBUMA) and Inherent Readiness (R_i) values for the new and the overhauled M35A2 2-1/2 ton cargo trucks through 20,000 miles of usage. The R_i values do not degrade and are approximately the same for the new and overhauled trucks; moreover, a test for differences of means revealed no significant difference between new and overhauled MMBUMA values at the .05 level of significance. One interesting sidelight noted in Figure 9.2 is that the lowest MMBUMA and R_i values occur during early life of the new and the overhauled vehicles. This is probably due to the initial quality control problems that generally occur in both new and overhauled vehicles. In summary, the overall MMBUMA values are 648 and 941, and the overall R_i values are .96 and .97 respectively, for the new and the overhauled vehicles.

9.3 Maintainability Analysis.

The object of this analysis was to determine if the man-hours required for maintenance were changing as the trucks increased in mileage. In addition, a parts replacement analysis was conducted. This latter analysis consisted of the following: (1) high cost (in excess of $200)

FIGURE 9.1

M35A2 2 1/2 TON CARGO TRUCK

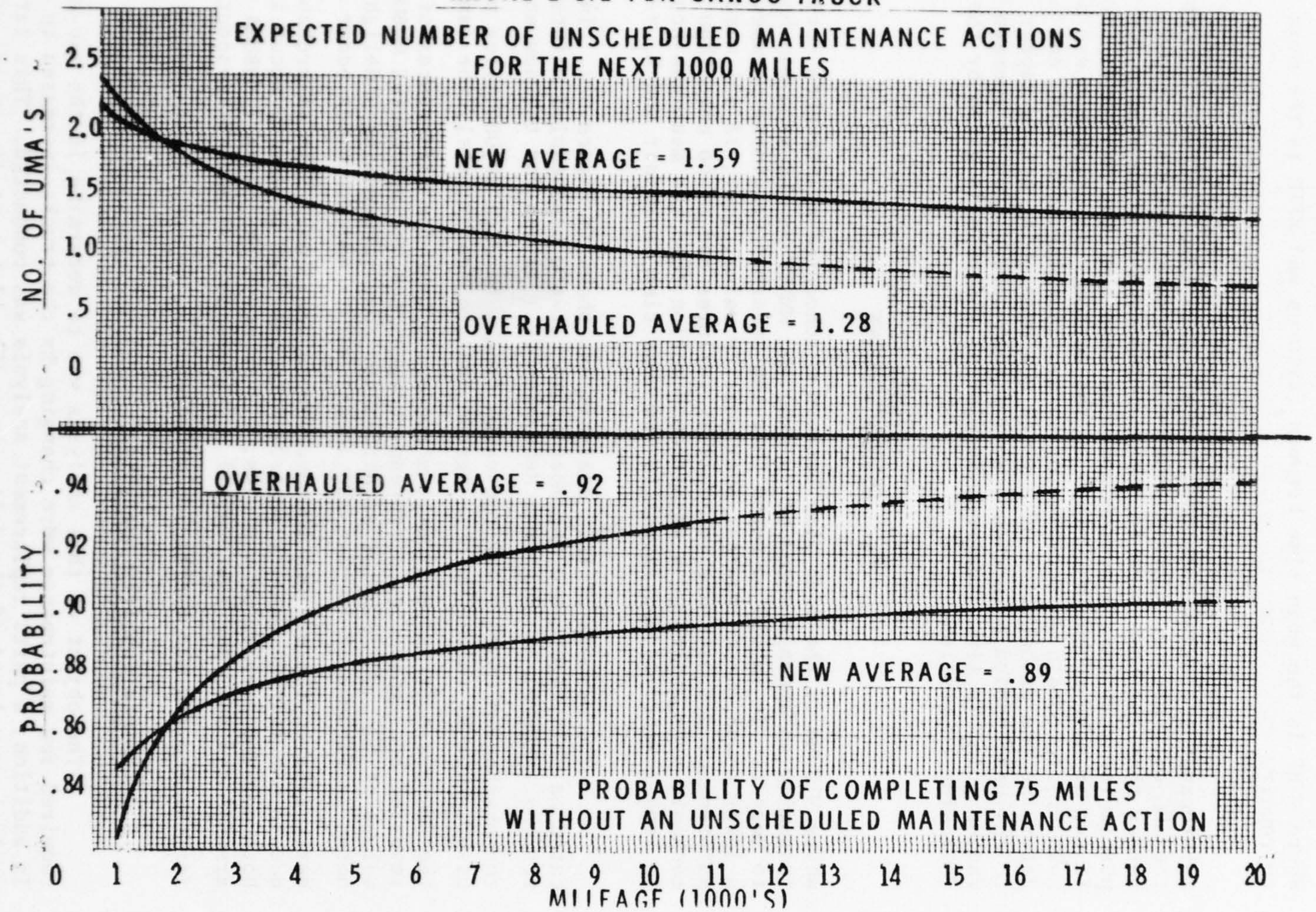


FIGURE 9.2
M35A2 2 1/2 TON CARGO TRUCK

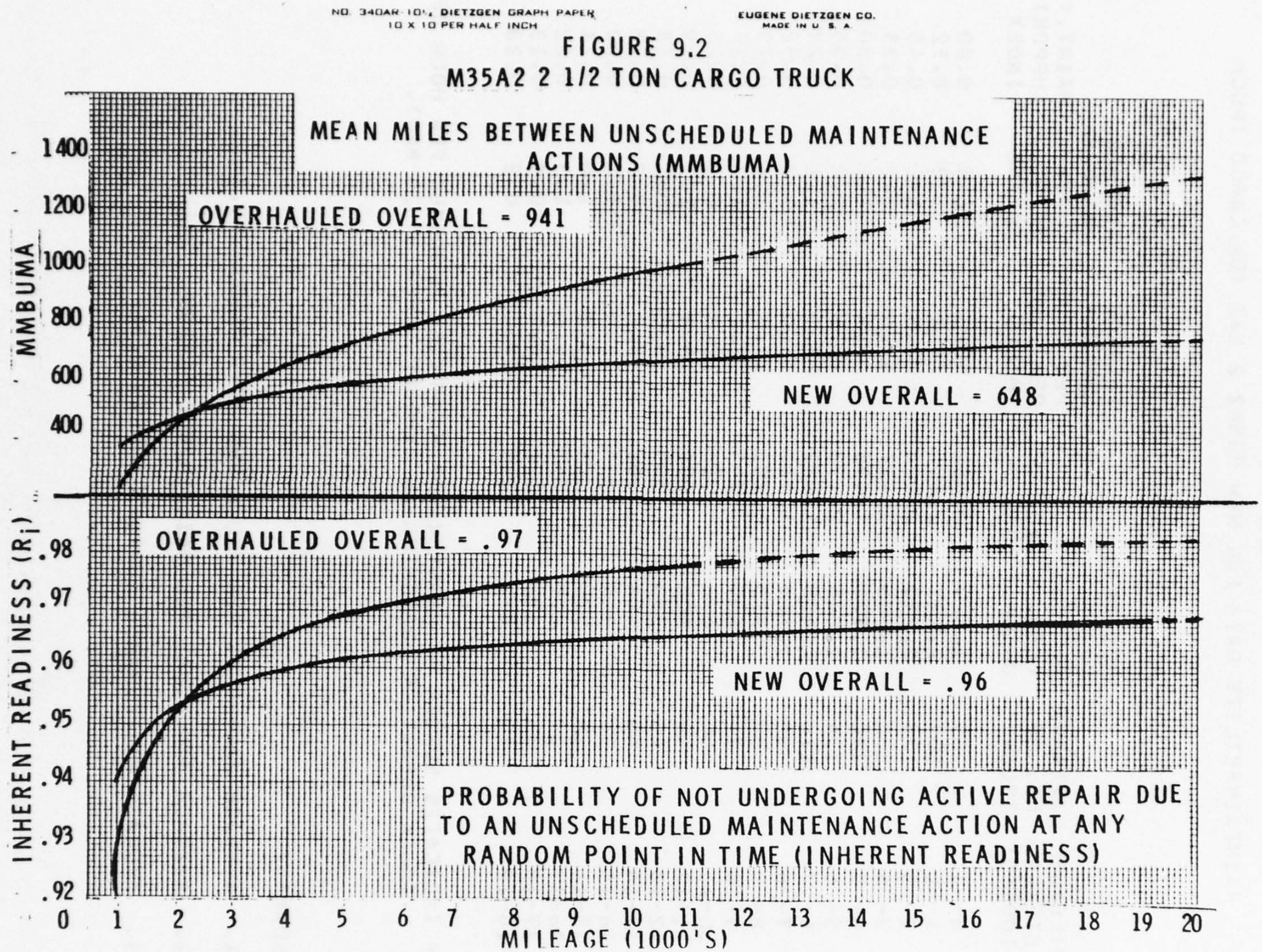


TABLE 9.1

MAINTAINABILITY DATA FOR NEW M35A2 2 1/2 TON CARGO TRUCK

MILEAGE INTERVAL (1000'S)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. + UNSCH.)	NO. OF MAN-HRS	AVERAGE MAN-HRS PER TRUCK PER 1000 MILES	AVERAGE MAN-HRS PER MAINT. ACTION	MAINT.* SUPPORT INDEX
0- 1	51	1,329	2,052	40.2	1.5	0.80
1- 2	107	2,221	2,804	26.2	1.3	0.52
2- 3	125	2,250	2,806	22.5	1.2	0.45
3- 4	138	1,986	2,426	17.6	1.2	0.35
4- 5	130	1,729	1,938	14.9	1.1	0.30
5- 6	124	1,805	2,173	17.5	1.2	0.35
6- 7	116	1,435	1,587	13.7	1.1	0.27
7- 8	98	1,164	1,564	16.0	1.3	0.32
8- 9	83	923	1,205	14.5	1.3	0.29
9-10	74	689	893	12.1	1.3	0.24
10-11	60	698	736	12.3	1.1	0.25
11-12	48	600	690	14.4	1.1	0.29
12-13	43	373	395	9.2	1.1	0.18
13-14	40	404	368	9.2	0.9	0.18
14-15	34	349	374	11.0	1.1	0.22
15-16	29	320	309	10.7	1.0	0.21
16-17	24	205	265	11.1	1.3	0.22
17-18	19	138	126	6.6	0.9	0.13
18-19	11	272	211	19.2	0.8	0.38

* INDICATES NUMBER OF MAINTENANCE MAN-HOURS REQUIRED PER HOUR OF TRUCK OPERATION (ASSUMING AN AVERAGE SPEED OF 20 MPH).

SUMMARY

1. AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES 15.7
2. AVERAGE MAN-HOURS PER MAINTENANCE ACTION 1.1
3. AVERAGE MAINTENANCE SUPPORT INDEX 0.31

TABLE 9.2

MAINTAINABILITY DATA FOR OVERHAULED M35A2 2 1/2 TON CARGO TRUCK

MILEAGE INTERVAL (1000'S)	AVERAGE NO. OF TRUCKS	NO. OF MAINT. ACTIONS (SCH. + UNSCH.)	NO. OF MAN-HRS	AVERAGE MAN-HRS PER TRUCK PER 1000 MILES	AVERAGE MAN-HRS PER MAINT. ACTION	MAINT.* SUPPORT INDEX
0- 1	221	5,525	7,231	32.7	1.3	0.65
1- 2	238	4,081	5,109	21.5	1.3	0.43
2- 3	208	3,486	4,134	19.9	1.2	0.40
3- 4	172	2,694	3,083	17.9	1.1	0.36
4- 5	131	1,819	1,859	14.2	1.0	0.28
5- 6	99	1,500	1,285	13.0	0.9	0.26
6- 7	79	960	801	10.1	0.8	0.20
7- 8	60	635	668	11.1	1.1	0.22
8- 9	42	306	328	7.8	1.1	0.16
9-10	26	161	159	6.1	1.0	0.12
10-11	16	66	99	6.2	1.5	0.12

* INDICATES NUMBER OF MAINTENANCE MAN-HOURS REQUIRED PER HOUR OF TRUCK OPERATION (ASSUMING AN AVERAGE SPEED OF 20 MPH).

SUMMARY

1. AVERAGE MAN-HOURS PER TRUCK PER 1000 MILES 14.6

2. AVERAGE MAN-HOURS PER MAINTENANCE ACTION 1.1

3. AVERAGE MAINTENANCE SUPPORT INDEX 0.29

TABLE 9.3

TEN MOST FREQUENTLY REPLACED PARTS FOR NEW AND OVERHAULED M35A2 2-1/2 TON CARGO TRUCK

	New			Overhauled		
Order	Nomenclature	Total Quantity Used	Replacement Rate Per 1000 Miles	Nomenclature	Total Quantity Used	Replacement Rate Per 1000 Miles
1	Lamp, Incandescent	243	.174	Lamp, Incandescent	429	.330
2	Boot, Steering Knuckle	203	.145	Seal, Plain Encased	190	.146
3	Battery, Storage, 12 Volt	153	.109	Battery, Storage 12 Volt	165	.127
4	Blade, Windshield Wiper	150	.107	Boot, Steering Knuckle	154	.118
5	Brake Shoe	104	.074	Cylinder Assembly, Hydraulic	121	.093
6	Cylinder Assembly, Hydraulic	96	.069	Blade, Windshield Wiper	110	.085
7	Arm, Windshield Wiper	89	.064	Arm, Windshield Wiper	87	.067
8	Motor, Windshield Wiper	82	.059	Corner Bow, Truck	83	.064
9	Clutch, Engine	69	.049	Bow, Vehicular Top	77	.059
10	Bearing, Ball	66	.047	Bracket, Angle	64	.049

Vehicle Mileage (Millions)

New 1.4
Overhauled 1.3

parts' replacements, (2) ten most frequently replaced parts, and (3) determination of the number of replacements for all vehicle parts.

10. PROFILES OF AVERAGE NEW AND OVERHAULED M35A2 2-1/2 TON CARGO TRUCKS

The average new M35A2 2-1/2 Ton Cargo Truck will sustain a total maintenance cost (for both scheduled and unscheduled maintenance) of $5,135 during the initial 20,000 miles of usage, for an average maintenance cost of 26¢ per mile. Over the same mileage, the overhauled M35A2 truck will cost $4,920 to maintain, for an average maintenance cost of 25¢ per mile.

During the initial 20,000 miles of usage, the average new truck will experience 32 UMA's with the mean miles between UMA's equal to 648 miles; whereas, the overhauled truck will undergo 26 UMA's with an average of 941 miles between UMA's. When the trucks are in the maintenance shop for UMA's, an average of 2.2 different parts will be repaired, replaced or adjusted on the new truck, and an average of 2.3 parts on the overhauled truck, during each UMA. In an average UMA, 1.1 man-hours of maintenance are expended on each part for the new vehicle, and 1.3 man-hours per part for the overhauled vehicle. The total man-hours per UMA average 2.3 for the new vehicle and 2.8 for the overhauled vehicle.

For each 1,000 miles of usage, an average of 12.0 man-hours of scheduled maintenance are required for the new truck, and 11.5 man-hours for the overhauled truck. On the same basis as above, the new vehicle incurs 3.7 man-hours of unscheduled maintenance, while the overhauled vehicle needs 3.1 man-hours of unscheduled maintenance. For every hour of truck operation (assuming an average speed of 20 miles per hour), the new vehicle requires an average of .31 man-hours of maintenance, and the overhauled vehicle requires .29 man-hours of maintenance.

Finally, there is a .96 probability that the average new truck will not be undergoing active repair due to an UMA at any point in time, and a .97 similar probability for the overhauled truck. The overall probability of completing 75 miles without having to go in for unscheduled repairs is .89 for the new vehicle and .92 for the overhauled vehicle.

11. PERFORMANCE OF OVERHAULED 2-1/2 TON TRUCKS OPERATED BY 25th INFANTRY DIVISION

During the early portion of this study, it was learned that the only other unit operating overhauled 2-1/2 ton trucks was the 25th Infantry Division in Hawaii. This division was not included in the SDC program because of the anticipated relatively low mileage accumulation of vehicles located in Hawaii. However, to supplement the data generated at Ft. Lewis, information on overhauled vehicles operated in Hawaii was sought.

In surveying the 25th Division for overhauled 2-1/2 ton trucks, 62 overhauled vehicles were located. An overhauled vehicle can be identified by means of a data plate that is secured to the dashboard. Although

TABLE 9.4

REPLACEMENT OF HIGH COST PARTS ($200, OR MORE) FOR
NEW AND OVERHAULED M35A2 2-1/2 TON CARGO TRUCK

			New		Overhauled	
NSN	Nomenclature	Cost (Dollars)	Total Quantity Used	Replacement Rate Per 1000 Miles	Total Quantity Used	Replacement Rate Per 1000 Miles
2815002395824	Engine	5651	14	.0100	17	.0131
2520007368511	Axle Assembly, Automotive	1183	2	.0014	1	.0008
4140007118354	Fan, Vane, Axial, Steel	737	1	.0007	0	.0000
2920007824156	Generator, Engine Accessories	717	9	.0064	4	.0031
2920003509402	Generator, Alternating	677	1	.0007	0	.0000
2520002572554	Housing, Mechanical	677	0	.0000	3	.0023
2530005251350	Steering Gear	642	1	.0007	0	.0000
2520008844833	Transmission	584	21	.0150	29	.0223
2910007595410	Pump, Fuel, Metering	570	10	.0071	31	.0238
2520003474520	Transmission	560	1	.0007	3	.0023
2520004466599	Transfer, Transmission	555	2	.0014	10	.0077
2910009086320	Pump, Fuel, Metering	547	1	.0007	1	.0008
2520007346970	Differential, Driving	525	1	.0007	1	.0008
2590007538687	Winch, Drum, Vehicular	381	6	.0043	5	.0038
4010004916990	Rope, Wire, 700 ft. length	274	1	.0007	5	.0038
2590006791423	Cable Assembly, Special	250	1	.0007	0	.0000
2920009092483	Generator, Engine	208	32	.0229	9	.0069
2940001295339	Air Cleaner Intake	204	15	.0107	7	.0054

Vehicle Mileage (Millions)

New	1.4
Overhauled	1.3

detailed maintenance data were not available for these trucks, certain noteworthy information was available, e.g., vehicle age, mileage accumulated and major component replacements.

Presented on Table 11.1 is a summary of the data gathered on these vehicles. As noted, the trucks varied in age up to 8 years, had accumulated nearly 300,000 miles and the only major component found to be replaced was the engine. As shown, eight engines were replaced on these vehicles with three of these engines replaced on a single truck within a one-month interval. In discussing this occurrence with maintenance personnel, it was revealed that at least two of the engines were replaced because of human error. For example, one of the engines was burned up because sufficient oil was not placed in the engine.

In general, as indicated by the data and based on discussions with personnel from the 25th Division, no unusual problems were found with these overhauled trucks. It is, in fact, pointed out that the 25th Division was unaware that the above 62 trucks were any different from the remainder of their vehicles.

TABLE 11.1

PERFORMANCE DATA ON OTHER OVERHAULED 2-1/2 TON TRUCKS
(OPERATED BY 25TH INFANTRY DIVISION, SCHOFIELD BARRACKS, HAWAII)

No. of Vehicles	Age of Overhauled Truck (Years)	Mileage Accumulated (1000's)	Total Mileage (1000's)	No. of Engines Replaced
0	0 - 1	0	0	0
10	1 - 2	0 - 8	23	1
9	2 - 3	0 - 5	26	0
33	3 - 4	0 - 9	121	4
6	4 - 5	2 - 19	50	1
3	5 - 6	7 - 25	47	1
0	6 - 7	0	0	0
1	7 - 8	24	24	1
62			291	8*

*Three of the engines were replaced on a single truck.

APPENDIX

A. GENERAL WEIGHTED MULTIPLE LINEAR REGRESSION

Under this analysis the data are considered to consist of k ordered (r+2) - tuples $(y_1, n_1, x_{11}, x_{12}, x_{13}, \ldots, x_{1r})$, $(y_2, n_2, x_{21}, x_{22}, x_{23}, \ldots, x_{2r}), \ldots, (y_k, n_k, x_{k1}, x_{k2}, x_{k3}, \ldots, x_{kr})$ where y_i is the i-th observation of the dependent variable (the variable to be predicted), n_i is the sample size for the i-th observation, and x_{ij} is the i-th observation for the j-th independent variable (variables to be used for future predictions) i=1,2,3,...,k and j=1,2,3,...,r. It is assumed that the dependent variable y_i can be expressed as a linear function of the x_{ij} plus a random variable ε_i. Thus, the model is

$$y_i = \beta_o + x_{i1}\beta_1 + x_{i2}\beta_2 + \ldots + x_{ir}\beta_r + \varepsilon_i.$$

However, since the precision of the i-th observation is dependent upon its sample size n_i, a transformation of the data is necessary to remove this dependency and obtain equality of variances. The model then becomes

$$y_i^* = x_{io}^*\beta_o + x_{i1}^*\beta_1 + x_{i2}^*\beta_2 + \ldots + x_{ir}^*\beta_r + e_i$$

where $y_i^* = \sqrt{n_i} y_i$

$x_{io}^* = \sqrt{n_i}$

$x_{ij}^* = \sqrt{n_i} x_{ij}$

or in matrix notation

$$\tilde{y} = \tilde{X}\tilde{\beta} + \tilde{e} \qquad (1)$$

where

$$\tilde{y} = \begin{bmatrix} y_1^* \\ y_2^* \\ \cdot \\ \cdot \\ y_k^* \end{bmatrix} \qquad \tilde{\beta} = \begin{bmatrix} \beta_o \\ \beta_1 \\ \cdot \\ \cdot \\ \beta_r \end{bmatrix} \qquad \tilde{e} = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ e_k \end{bmatrix}$$

$$\tilde{X} = \begin{bmatrix} x_{10}^* & x_{11}^* & x_{12}^* & \cdots & x_{1r}^* \\ x_{20}^* & x_{21}^* & x_{22}^* & \cdots & x_{2r}^* \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ x_{ko}^* & x_{k1}^* & x_{k2}^* & \cdots & x_{kr}^* \end{bmatrix}$$

The e_i are assumed to be uncorrelated ($E(e_ie_j) = 0$ for $i \neq j$) and normally distributed random variables with mean zero and variance σ^2. The independent variables are assumed to be controlled or measured accurately and are therefore relatively free of error. The unknown parameters in the model $\beta_0, \beta_1, \beta_2, \ldots, \beta_r$ are estimated by the method of least squares. Let $\tilde{b} = (b_o, b_1, b_2, \ldots, b_r)^T$ be the column vector of the required estimates, then these estimates have the property that they minimize the expression

$$S = \sum_{i=1}^{k} (y_i^* - \sum_{j=0}^{r} x_{ij}^* b_j)^2$$

or in matrix notation

$$S = || \tilde{y} - \tilde{X}\tilde{b} ||^2 \qquad (2)$$

where $||v||$ denotes the norm of the vector v.

In order to find the required estimates of β_2 ($\nu = 0,1,2,\ldots,r$), we set the partial derivates of S with respect to b_ν equal to zero.

$$\frac{\partial S}{\partial b_\nu} = -2 \sum_{i=1}^{k} (y_i^* - \sum_{j=0}^{r} x_{ij}^* b_j) x_{i\nu} = 0$$

or

$$\sum_{i=1}^{k} \sum_{j=0}^{r} x_{i\nu}^* x_{ij}^* b_j = \sum_{i=1}^{k} x_{i\nu}^* y_i^* .$$

These r+1 simultaneous equations corresponding to $\nu = 0,1,2,\ldots.r$ are called the normal equations in regression analysis. In matrix notation the normal equations may be written.

$$\tilde{X}^T \tilde{X} \tilde{b} = \tilde{X}^T \tilde{y} \tag{3}$$

where $\tilde{X}^T$ is the transpose of $\tilde{X}$.

$$\text{Let } (\tilde{X}^T\tilde{X})^{-1} = \begin{bmatrix} c_{00} & c_{01} & c_{02} & \cdots & c_{0r} \\ c_{10} & c_{11} & c_{12} & \cdots & c_{1r} \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdot & \cdots & \cdot \\ c_{r0} & c_{r1} & c_{r2} & \cdots & c_{rr} \end{bmatrix}$$

be the inverse of the matrix $\tilde{X}^T\tilde{X}$. Then the required estimate of $\tilde{\beta}$ is given by

$$\tilde{b} = \left(\tilde{X}^T\tilde{X}\right)^{-1} \tilde{X}^T \tilde{y} \tag{4}$$

Since the b_j ($j = 0,1,2,\ldots,r$) are only estimates of the unknown constants β_j, computed from the observed data, they are subject to variation if a new set of data became available and the same procedure was applied to

these data. Then the b_j are random variables and it can be shown that the mean or expected value of b_j is equal to β_j, i.e., $E(b_j) = \beta_j$. Estimates of the standard deviation of b_j are obtained as follows:

$$s_{b_0} = s\sqrt{c_{00}} \tag{5}$$

$$s_{b_1} = s\sqrt{c_{11}}$$

$$\vdots$$

$$s_{b_r} = s\sqrt{c_{rr}}$$

where

$$s = \sqrt{\frac{1}{k-r-1}\left[\tilde{y}^T\tilde{y} - \tilde{b}\tilde{X}^T\tilde{y}\right]} \tag{6}$$

Under the assumptions made for the regression model, $(b_j - \beta_j)/s_{b_j}$ has the Student's t-distribution with k-r-1 degrees of freedom. This fact can be used to construct a confidence interval estimate of the unknown parameter β_j. Then

$$b_j \pm t_{1-\frac{\alpha}{2},\, k-r-1}\, s_{b_j} \tag{7}$$

is a $(1-\alpha)$ 100% confidence interval for β_j, where $t_{1-\frac{\alpha}{2},\, k-r-1}$ is the $1-\frac{\alpha}{2}$ percentile of the Student's t-distribution with k-r-1 degrees of freedom[1]. The interpretation of this interval is that if intervals of this type are repeatedly constructed following this procedure, $(1-\alpha)$ 100% of these intervals will contain the population parameter β_j being estimated. This confidence interval can also be used to test the hypothesis that $\beta_j = \beta^0$ where β^0 is a given constant. If the interval obtained from Equation (7) contains β^0, then we would accept the hypothesis H_0: $\beta_j = \beta^0$. If the interval does not contain β^0, then we would reject this hypothesis. This test criterion has the property that if β_j actually equals β^0 then the probability that the hypothesis H_0: $\beta_j = \beta^0$ will be rejected is equal to α (assuming a $(1-\alpha)$ 100% confidence interval) and the probability that H: $\beta_j = \beta^0$ will be

rejected if β_j equals any other given number can be computed using the non-central t-distribution[2]. An important special case is that of the null hypothesis, i.e., $H_0 = \beta_j = 0$. If based on a test of significance H_0: $\beta_j = 0$ is accepted, β_j might be considered to be dropped from the model since it does not appear to be making a significant contribution to the estimation of the dependent variable.

Under the original model, the mean or expected value of y for a given value of $(x_1, x_2, \ldots, x_r)$ is

$$E(y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_r x_r$$

where β_0, β_1, $\beta_2, \ldots, \beta_r$ are the unknown parameters to be estimated. Thus,

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_r x_r \tag{8}$$

gives an estimate of the mean value of y for a given value of $(x_1, x_2, \ldots, x_r)$.

B. COMPARISON OF TWO REGRESSION LINES

For this analysis, the data are considered to consist of two sets of 2-tuples

$$(x_{11}, y_{11}),\ (x_{21}, y_{21}), \ldots,\ (x_{i1}, y_{i1}), \ldots,\ (x_{n_1 1}, y_{n_1 1})$$

and

$$(x_{12}, y_{12}),\ (x_{22}, y_{22}), \ldots,\ (x_{j2}, y_{j2}), \ldots,\ (x_{n_2 2}, y_{n_2 2})$$

where the y_{i1} and y_{j2} (dependent variables) can be expressed as linear functions of the x_{i1} and x_{j2} (independent variables) plus random variables e_{i1} and e_{j2} respectively.

Thus,

$$y_{i1} = \beta_{o1} + x_{i1}\beta_{11} + e_{i1}$$

and

$$y_{j2} = \beta_{o2} + x_{j2}\beta_{12} + e_{j2}$$

or in matrix notation

$$\tilde{y}_k = \tilde{X}_k \tilde{\beta}_k + \tilde{e}_k \qquad k = 1,2$$

where

$$\tilde{y}_k = \begin{bmatrix} y_{1k} \\ y_{2k} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ y_{n_k k} \end{bmatrix} \qquad \tilde{\beta}_k = \begin{bmatrix} \beta_{ok} \\ \beta_{1k} \end{bmatrix} \qquad \tilde{e}_k = \begin{bmatrix} e_{1k} \\ e_{2k} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ e_{n_k k} \end{bmatrix}$$

$$\tilde{X}_k = \begin{bmatrix} 1 & x_{1k} \\ 1 & x_{2k} \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ 1 & x_{n_k k} \end{bmatrix}$$

Utilizing the method of least squares (see Appendix A), $\hat{\beta}_k$ is estimated by

$$\tilde{b}_k = (\tilde{X}_k^T \tilde{X}_k)^{-1} \tilde{X}_k^T \tilde{y}_k \qquad k = 1,2$$

where

$$(\tilde{X}_k^T \tilde{X}_k)^{-1} = \begin{bmatrix} c_{oo} & c_{ok} \\ c_{ko} & c_{kk} \end{bmatrix}$$

Estimates of the standard deviations of $\tilde{b}_k$ are

$$s_{b_{ok}} = s_k \sqrt{c_{oo}}$$

$$s_{b_{1k}} = s_k \sqrt{c_{kk}}$$

where

$$s_k = \sqrt{\frac{1}{n_k - 2} \left[\tilde{y}_k^T \ \tilde{y}_k - \tilde{b}_k \ \tilde{X}_k^T \ \tilde{y}_k \right]} \qquad k = 1,2$$

is an estimate of the standard deviation σ_k of the random variables e_k.

To test whether a single linear function with common variance σ^2 can represent both sets of data, the null hypothesis that s_1^2 and s_2^2 are estimates of σ^2 is first tested. Under the null hypothesis, s_1^2/s_2^2 has the Snedecor's F-distribution with n_1-2 and n_2-2 degrees of freedom. If the null hypothesis is rejected, then the linear functions differ in this regard. However, if the null hypothesis of a common variance σ^2 is accepted, then

$$s^2 = \frac{(n_1-2)s_1^2 + (n_2-2)s_2^2}{n_1 + n_2 - 4}$$

provides a pooled estimate of σ^2.

The next test is that the slopes, β_{11} and β_{12} are equal. Under the null hypothesis $\beta_{11} - \beta_{12} = 0$, $b_{11} - b_{12}$ has the normal distribution with mean 0 and variance

$$\sigma^2 \ (c_{11} + c_{22})$$

where σ^2 is estimated by s^2. Therefore, under the null hypothesis $\beta_{11} - \beta_{12} = 0$

$$\frac{b_{11} - b_{12}}{s\sqrt{c_{11} + c_{22}}}$$

has the Student's t-distribution with $n_1 + n_2 - 4$ degrees of freedom. If this null hypothesis is rejected, then the lines differ in slope. If the null hypothesis is accepted, the linear functions

$$y_{i1} = \beta_{o1} + x_{i1}\beta_1 + e_{i1}$$

and

$$Y_{j2} = \beta_{o2} + x_{j2}\beta_1 + e_{j2}$$

with common slope β_1 are estimated from the two sets of data.

In matrix notation, these functions are

$$\tilde{y} = \tilde{X}\tilde{\beta} + \tilde{e}$$

where

$$\tilde{y} = \begin{bmatrix} y_{11} \\ y_{21} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ y_{n_1 2} \\ y_{12} \\ y_{22} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ y_{n_2 2} \end{bmatrix} \qquad \tilde{\beta} = \begin{bmatrix} \beta_{o1} \\ \beta_{o2} \\ \beta_1 \end{bmatrix} \qquad \tilde{e} = \begin{bmatrix} e_{11} \\ e_{21} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ e_{n_1 1} \\ e_{12} \\ e_{22} \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ e_{n_2 2} \end{bmatrix}$$

$$\tilde{X} = \begin{bmatrix} 1 & 0 & x_{11} \\ 1 & 0 & x_{21} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 1 & 0 & x_{n_1 1} \\ 0 & 1 & x_{12} \\ 0 & 1 & x_{22} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 0 & 1 & x_{n_2 2} \end{bmatrix}$$

From the method of least squares, $\tilde{\beta}$ is estimated by

$$\tilde{b} = (\tilde{X}^T \tilde{X})^{-1} \tilde{X}^T \tilde{y}$$

where

$$(\tilde{X}^T \tilde{X})^{-1} \begin{bmatrix} d_{oo} & d_{o1} & d_{o2} \\ d_{10} & d_{11} & d_{12} \\ d_{20} & d_{21} & d_{22} \end{bmatrix}$$

Estimates of the standard deviations of $\tilde{b}$ are

$$s_{b_{o1}} = s\sqrt{d_{oo}}$$

$$s_{b_{o2}} = s\sqrt{d_{11}}$$

$$s_{b_1} = s\sqrt{d_{22}}$$

where

$$s = \sqrt{\frac{1}{n_1 + n_2 - 3} \left[\tilde{y}^T \tilde{y} - \tilde{b}\tilde{X}^T \tilde{y}\right]}$$

is an estimate of the standard deviation σ for these two linear functions with common slope β_1.

The final test in determining whether a single linear function with common variance σ^2 can represent both sets of data is that the intercepts, β_{o1} and β_{o2} are equal. Under the null hypothesis $\beta_{o1} - \beta_{o2} = 0$, $b_{o1} - b_{o2}$ has the normal distribution with mean 0 and variance

$$\sigma^2(d_{oo} + d_{11})$$

where σ^2 is estimated by s^2. Thus,

$$\frac{b_{o1} - b_{o2}}{s\sqrt{d_{oo} + d_{11}}}$$

has the Student's t-distribution with $n_1 + n_2 - 3$ degrees of freedom.

If the null hypothesis is rejected, then the lines differ in intercept. However, if the null hypothesis is accepted, the single linear function

$$y_{kl} = \beta_o + x_{kl}\beta_1 \qquad k = i,j \qquad l = 1,2$$

can be used to represent both sets of data where β_o and β_1 are estimated by the method of least squares from the combined data.

C. DATA PROCESSING PROCEDURES

The data processing was conducted at Aberdeen Proving Ground using the Ballistic Research Laboratories Electronic Scientific Computers (BRLESC I and II) which are described in Campbell, et al., 1970. The programs and routines utilized in the study were written in FORTRAN, OMNITAB II, and RPG II. OMNITAB II is a sophisticated, highly user-oriented, FORTRAN based, computing system which uses English-like commands to perform a wide variety of numerical and statistical calculations. OMNITAB II is available on many large computers and is documented in Hogben, et.al., (1971). RPG II is a fixed form programming language widely used for its ease and flexibility in producing computer output in report format. Since a compiler for RPG II was not available on BRLESC, a language processor program for RPG II was developed and written in FORTRAN. This RPG Processor accepts as data and executes routines written in RPG II. This system was used to produce a number of the tables in this report.

The flowchart shown in Figure A.1 represents the major programs and routines, the input and output relations, the large computer-generated documents, and the important operations involved in the automated processing accomplished for the study. The SDC histories used in this study were received from the U.S. Army DARCOM Maintenance Readiness Support Activity (MRSA) on magnetic computer tape in IBM BCD code. The two data tapes were translated to BRLESC bit code and then decoded into a more readable, columnarized and labelled form written onto output tapes from which a paper copy was printed. These decoded tapes were then screened for errors.

The screening and correction of the basic data involved placing the lines of each vehicle history in order of date and checking the mileage sequence. A history with a single mileage discrepancy was corrected by replacing the mileage entry in question by the mean of the prior and subsequent mileage entries. Two or more mileage discrepancies caused the vehicle under examination to be deleted from further consideration in the study. The data were subsequently screened for large gaps between reporting dates (missing quarters) and only that portion of each history free of intermittent reporting was accepted for use. Only a few of the vehicles in the original set of histories had such errors as described above.

From the corrected history tapes, various summaries were produced, and a file of replacement parts was accumulated. The National Stock Numbers (NSN's) collected were used by the U.S. Army DARCOM Catalog Data Activity (USADCDA) to search the Army Master Data File (AMDF) to obtain unit price, unit of issue, and correct nomenclature for each of the parts replaced.

The processing of the data included the determination of the following: the usage rate of each vehicle; the mileage interval covered by each vehicle; the average number of, and man-hours expended for each maintenance action; the rate of unscheduled maintenance actions; the total frequency of each part replaced; and the cost of maintenance by 100 mile intervals. Additionally, a weighted polynomial regression curve fitting procedure was applied to the cost data.

FIGURE A.1

SYSTEM FLOWCHART

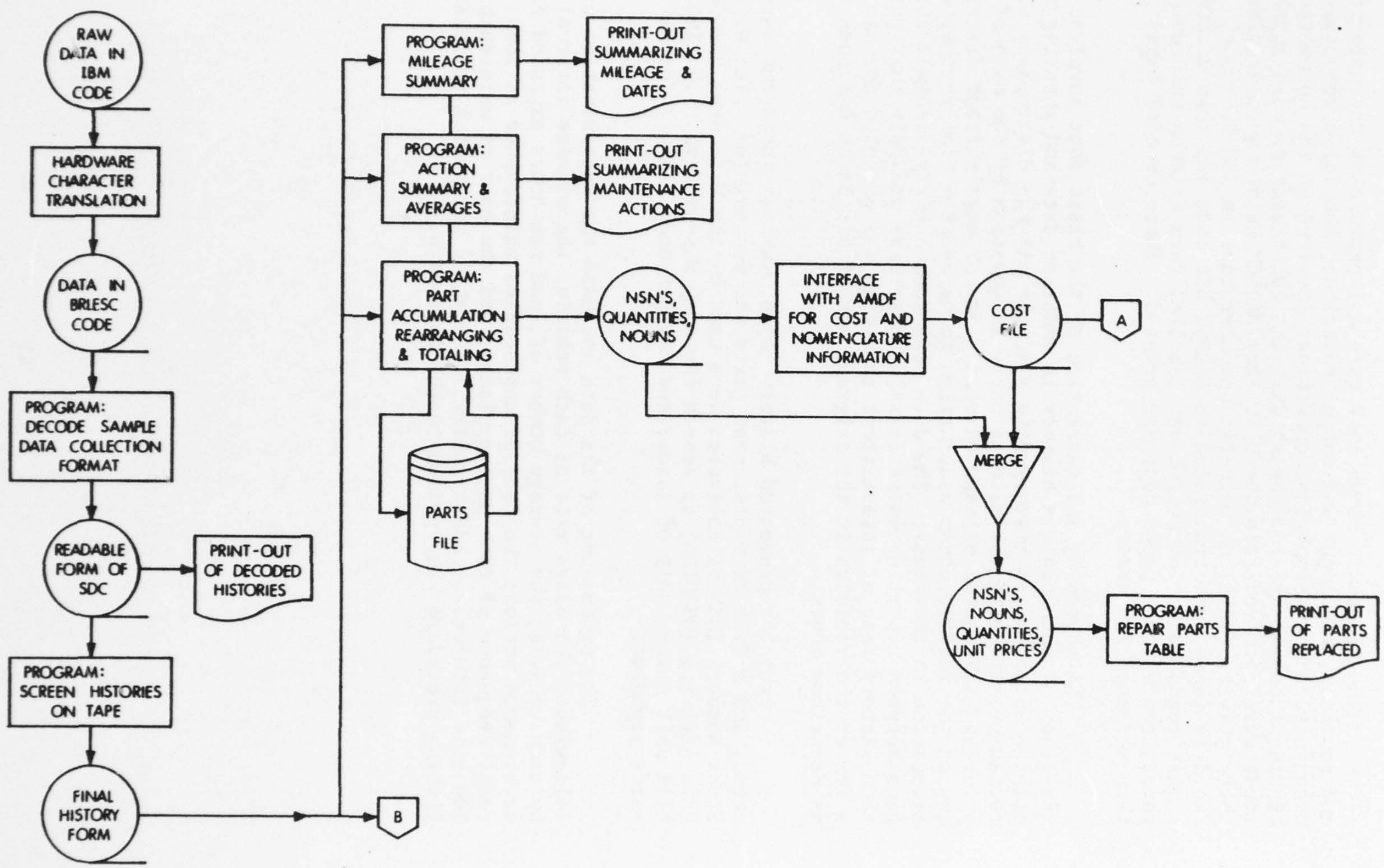
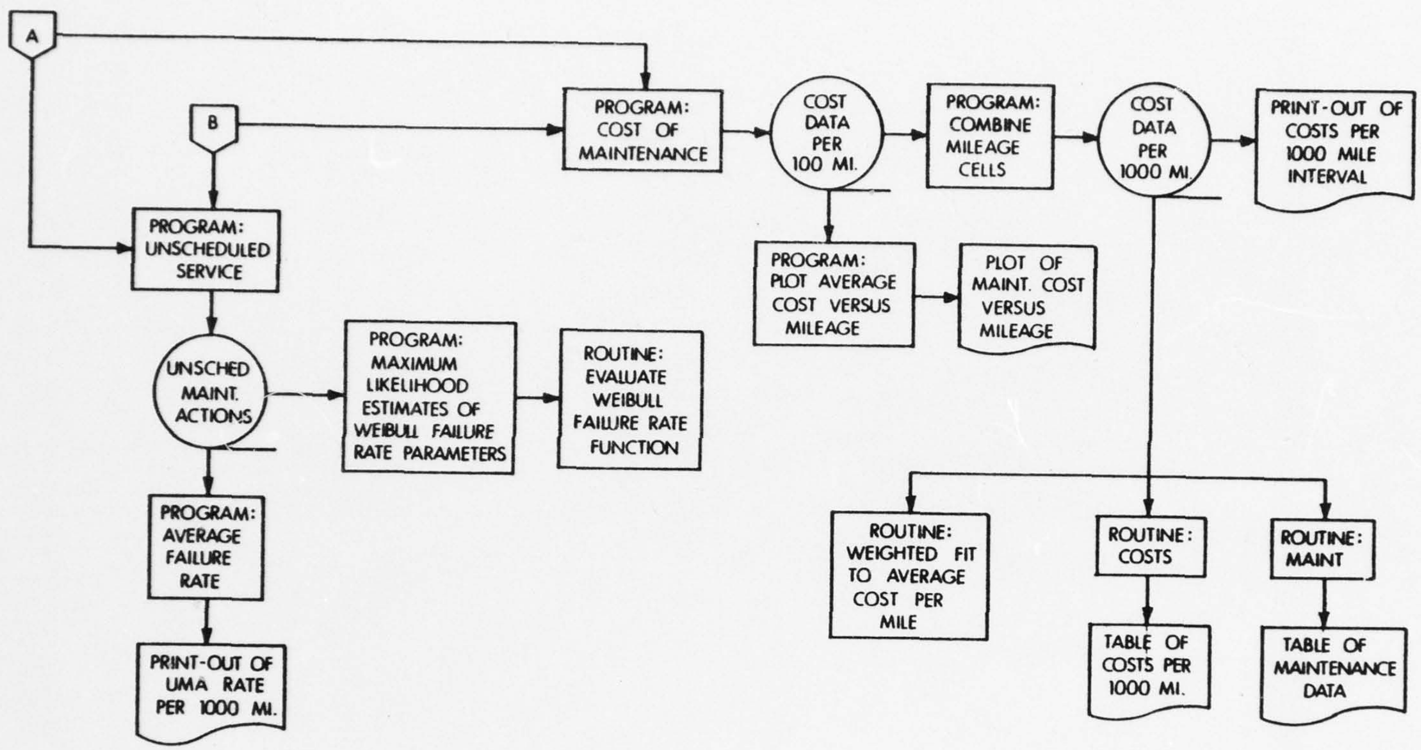


FIGURE A.1 (CONTINUED)

SYSTEM FLOWCHART (CONTINUED)



Next page is blank.

REFERENCES

1. Belbot, E. F., A Computer Program for Estimation of Parameters of the Weibull System Failure Rate Function, AMSAA Technical Report No. 99, May 1974.

2. Belbot, E. F., Computer Documentation for the Vehicle Average Useful Life Study, AMSAA Technical Report No. 141, August 1975.

3. Bell, Raymond; Mioduski, Robert E.; Belbot, Edward F., Vehicle Useful Life Study for Truck, 1/4 Ton, 4x4, M151A1/A2, AMSAA Technical Report No. 219, October 1977.

4. Bell, Raymond; Mioduski, Robert E.; Belbot, Edward F., Vehicle Average Useful Life Study for Truck, 5 Ton, 6x6, M39A2 Series, AMSAA Technical Report No. 128, June 1975.

5. Bell, Raymond; Mioduski, Robert E.; Belbot, Edward F.; Rosati, Robert A.; Crow, Larry H., Vehicle Average Useful Life Study for Truck, Cargo: 2-1/2 Ton, 6x6, M35A2, AMSAA Technical Memorandum No. 163, October 1973.

6. Campbell, L. W. and Beck, G. A., BRLESC I/II FORTRAN, U.S. Army Aberdeen Research and Development Center Technical Report No. 5, 1970.

7. Crow, Larry H., Weibull Reliability Procedures for Complex, Repairable Systems, AMSAA Technical Report No. 81, December 1975.

8. Hogben, D.; Leavy, S. T., and Varner, R. N., OMNITAB II User's Reference Manual, National Bureau of Standards Technical Note No. 552, 1971.

9. Stonier and Hague, Economic Theory, John Wiley and Sons, Inc., New York, 1953.

10. AR 750-1, Army Materiel Maintenance Concepts and Policies, 1 April 1978.

Next page is blank.

DISTRIBUTION LIST

No. of Copies	Organization
12	Commander Defense Documentation Center ATTN: TCA Cameron Station Alexandria, VA 22314
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCCP 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCDE-F 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCRE-I 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCBSI-L 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCPA-S 5001 Eisenhower Avenue Alexandria, VA 22333

DISTRIBUTION LIST (CONTINUED)

No of Copies	Organization
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCQA 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCBSI-D 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCDE-R 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCMM-MS (MAJ J. Hughes) 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Materiel Development & Readiness Command ATTN: DRCDE-D 5001 Eisenhower Avenue Alexandria, VA 22333
10	HQDA(DALO-SMD, LTC R. Healey) WASH DC 20314

DISTRIBUTION LIST (CONTINUED)

No. of Copies	Organization
5	HQDA(DALO-SML, Mr. W. Nicols) WASH DC 20310
1	Commander US Army Tank-Automotive Materiel Readiness Command ATTN: DRSTA-MSA (CAPT R. Sirtak) Warren, MI 48090
1	Commander US Army Tank-Automotive Materiel Readiness Command ATTN: DRSTA-VL (Mr. D. Palmer) Warren, MI 48090
1	Commander US Army Maintenance Management Center ATTN: DRXMD-MT (Mr. E. Jackson) Lexington, KY 40507
1	Commander US Army Armament Materiel Readiness Command ATTN: DRSAR-SA Rock Island, IL 61299
1	Commander Rock Island Arsenal ATTN: (Tech Lib) Rock Island, IL 61299
1	Commander Harry Diamond Laboratories ATTN: DELHD-SAB 2800 Powder Mill Road Adelphi, MD 20783
1	Commander US Army Test & Evaluation Command ATTN: STEDP-MT-L Dugway Proving Ground, UT 84022

DISTRIBUTION LIST (CONTINUED)

No. of Copies	Organization
1	Commander US Army Aviation R&D Command ATTN: DRDAV-BC P.O. Box 209 St. Louis, MO 63166
1	Commander US Army Electronics R&D Command ATTN: DRSEL-SA Fort Monmouth, NJ 07703
2	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL ATAA-T White Sands Missile Range, NM 88002
1	Commander US Army Missile R&D Command ATTN: DRDMI-C Redstone Arsenal, AL 35809
1	Commander US Army Troop Support & Aviation Materiel Readiness Command ATTN: DRSTS-BA 4300 Goodfellow Blvd. St. Louis, MO 63120
2	Commander US Army Tank-Automotive R&D Command ATTN: DRDTA-UL (Tech Lib) DRDTA-V Warren, MI 48090
1	Commander US Army Mobility Equipment R&D Command ATTN: DRDME-O Fort Belvoir, VA 22060

DISTRIBUTION LIST (CONTINUED)

No. of Copies	Organization
1	Commander US Army Natick R&D Command ATTN: DRDNA-O Natick, MA 01760
2	Chief, Defense Logistics Studies Information Exchange US Army Logistics Management Center ATTN: DRXMC-D Fort Lee, VA 23801
1	Commandant US Army Transportation School ATTN: ATSP-CD-CS (MAJ Andresen) Ft. Eustis, VA 23604
1	Commander US Army Concepts Analysis Agency 8120 Woodmont Avenue Bethesda, MD 20014
1	Reliability Analysis Center ATTN: Mr. I. L. Krulac Griffis Air Force Base, NY 13441
	Aberdeen Proving Ground
	Cdr, USATECOM ATTN: DRSTE, DRSTE-CS-A Bldg 314
	Dir, BRL, STINFO Br., Bldg 305
	Dir, BRL, Bldg 328
	Dir, HEL, Bldg 520